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Hurricane flooding and water quality issues: opportunities for increased resilience

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Motivation and objectives

Hurricanes are often accompanied by poor water quality threatening humans and aquatic species[1-5] (e.g., Fig. 1), yet impacts are difficult to measure[6]. Increased storm frequency and intensity, coupled with ongoing land use change, will exacerbate impacts to vulnerable communities and ecological systems[6-8]. North Carolina experienced two '500-yr' storms 2016-2018, presenting a timely case for assessing floodplain resilience to inform interventions. Flood extent mapping can help to quantify potential impacts[9].

Figure 1. Hurricane-related water quality issues include low oxygen and fish kills (A: Lock & Dam 1, Cape Fear River) and widespread distribution of harmful contaminants (B: swine facility near Kinston, NC).

Objectives:

1) **Delineate flooding from Hurricanes Matthew (2016) and Florence (2018).**
2) **Assess implications of differences between exposure compared to hazard maps vulnerable human communities and freshwater networks.**
3) **Identify opportunities to reduce future flooding and water quality problems.**

Methods

- We mapped flood extent with Sentinel-1 radar[10], topography[11-13], landcover[14,15], and floodplain[16] data using random forest models[17] in Google Earth Engine[18]. We used high-resolution aerial photography[19] and high water marks[20,21] for model validation.
- To examine potential impacts on vulnerable human populations[22] and freshwater networks[23] across flood hazard and exposure areas, we used quantile regression[24].
- We identified flood-prone pollutant sources[25,26] and water supply and treatment infrastructure; in addition we mapped locations where nature-based solutions could reduce flooding and improve water quality.

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Hazard mapping underestimated impacts on vulnerable systems

Across the Piedmont and Coastal Plain of North Carolina, we identified hurricane flooding (>91% accuracy) beyond hazard zones—Hurricane Florence exceeded the 1% annual probability zone by ~23% (Fig. 2). Furthermore, the legal floodplain underestimated impacts for communities with higher proportions of older adults, disabilities, unemployment, and mobile homes, as well as for headwater streams with restricted elevation gradients.

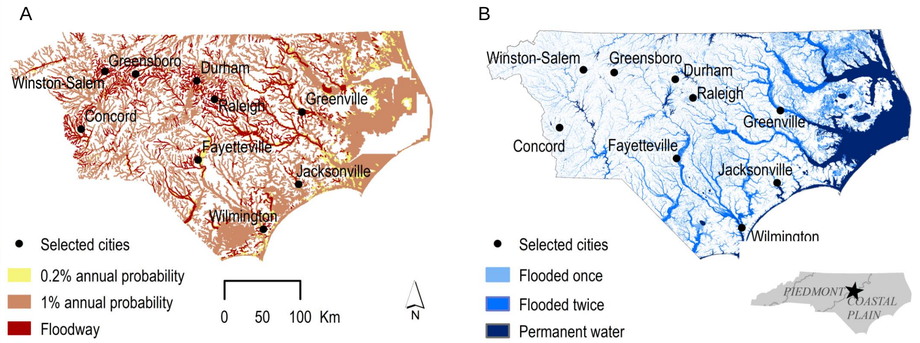
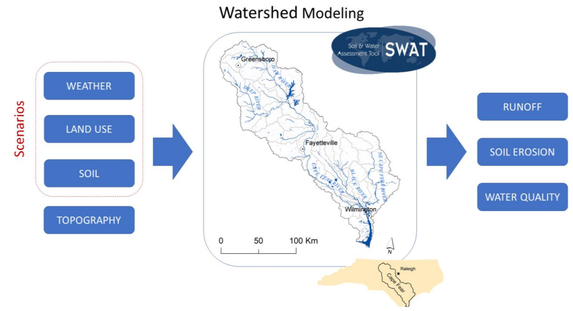


Figure 2. Areas well beyond state mapped flood hazard zones (A: 0.2% probability = '500-yr' floodplain, 1% annual probability = '100-yr floodplain) were affected by flooding from Hurricanes Matthew and Florence, as detected with Sentinel-1 SAR (B).

Implications and Next Steps

- **Results suggest that current hazard mapping is inadequate for resilience planning to protect vulnerable systems.**
- **Modification of design standards, land-use policies, and operation of infrastructure that conveys and treats water and pollutants are warranted.**
- **Interventions will be more thoroughly assessed using a Soil and Water Assessment Tool Model[27] in collaboration with the U.S. Geological Survey.**



Potential impacts and opportunities

Repeated flooding affected numerous potential sources of water contaminants, including 218 wastewater treatment plants (~55% capacity), and 91 swine farms (~500 million tons/yr manure). To illustrate potential impacts due to flooding beyond the 100-yr floodplain (1% annual probability), we use the example of nutrient sources subject to distinct regulatory limitations, including wastewater treatment plants (National Pollution Discharge Elimination System [NPDES] permitted point-source), swine facilities (NPDES permitted point-source, or non-point source) and poultry facilities (non-point source) (Fig. 3). We also identified ~4.8 million km^2 of forests and wetlands lacking formal protection, and ~1.7 million km^2 of working lands where restoration or management changes could be considered.

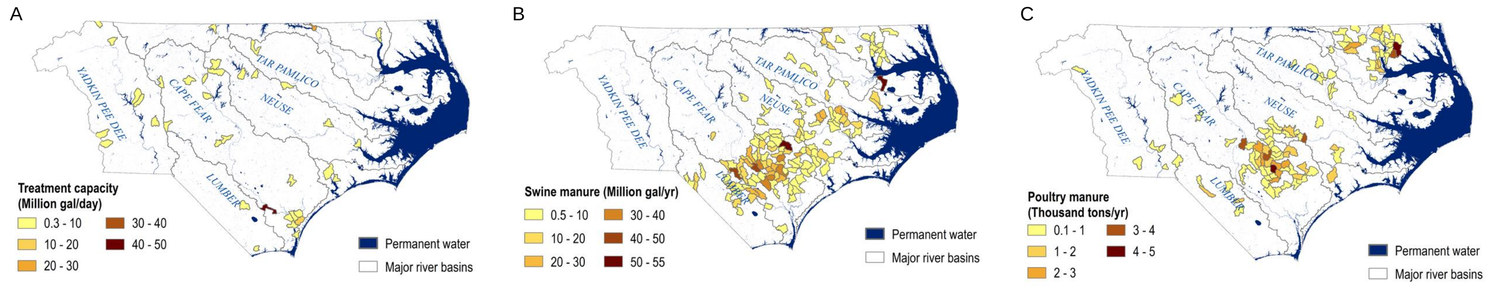


Figure 3. Potential nutrient load by watershed from facilities beyond the '100-yr' floodplain affected by Hurricanes Florence and Matthew. A: Permitted wastewater treatment plants. B: Permitted swine farms, which also include lands where waste is regularly applied. C: Poultry farms not regulated by NPDES.

Copernicus Sentinel-1 SAR data were processed by ESA. Applied Flow Technology provided modeled 1,000-year floodplain data. The Environmental Working Group provided poultry facility location data. Funding was provided by a NatureNet Science Fellowship.

Photo: NASA Landsat 8 image of the Trent River, North Carolina, September 19, 2018.